SOME EFFECTS OF DREDGING AND SAND MINING ON WATER QUALITY, CORAL REEFS, SEA GRASSES AND EASTERN CARIBBEAN COASTAL ENVIRONMENTS

David Grigg
William Rainey
Edward Towle

Island Resources Foundation
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Nature has a finite ability to tolerate changes and to maintain desirable conditions. This ability can be overtaxed and when individual organisms or whole systems are stressed beyond their tolerance limits disaster results. From this we can gain perhaps a better understanding of the word pollutant. A pollutant may be defined as any material which causes a change in the environment which is either too great to be tolerated by the system or by some individual species or which results in modifications which are undesirable. Sediment caused by dredging in the sea can be a pollutant. The purpose of this paper is to discuss some of the effects of this type of pollution resulting from uncontrolled dredging of sand from near or off-shore waters.

Coral Reefs

Living coral reefs, because of their particular sensitivities, their intimate relationships with sand production, and their general importance to Caribbean economy deserve our concerned interest. Reefs are not only scenic, but are structurally and economically important. West Indian fishing is centered largely around reef complexes.

The reef and its associated flora and fauna provide food and shelter for the young and adults of most of the regional seafood species. Sea sand, produced primarily by reef-building organisms, is in demand for making concrete, especially on smaller islands which lack terrigenous sand deposits. With increasing development in the Caribbean the demand for sand increases, but we have no reason to believe that its production in the sea is increasing. Many reefs, by their location, afford considerable protection to leeward coastal features by abating oncoming oceanic waves.

Sea sand is largely $CaCO_3$, although there are regional variations in its content of weathered silicate rock and volcanic ash in nearshore deposits. This $CaCO_3$ is precipitated from sea water by various marine organisms as part of their natural processes to make skeletal material. When such organisms are broken, eroded, or die, the skeletal parts break down to form sand grains.

Corals, of course, are the greatest source of this material, especially in the tropics where large reef-forming stony corals abound. Calcareous algae also contribute greatly to sand deposits and in some areas extremely large volumes of coarse algal fragments have accumulated over the years.

Sand production depends on a very closely knit complex. The major contributors, corals, also provide the habitat for many of the minor contributors, including those which carry on the erosive processes. These are animals which bore into the coral to make their homes and those which eat it or other calcareous organisms. It has been estimated that fishes alone, by browsing on calcareous organisms are excreting the undigestible sand particles, contribute approximately 2.5 tons/acre/yr. of sand.

Sand therefore, is a renewable natural resource. Further, we cannot disregard the fact that it is economically valuable and can be harvested to good advantage. The problems associated with mining of sea-sand are, in a way, similar to those of logging trees, catching fish, or trawling shrimp. The rate of harvesting must not exceed the rate of production and the source of production must not be destroyed.

In the Caribbean we have had many instances of marine resources destruction caused by such operations, but only recently have begun to investigate these effects and make an effort to describe the results, mostly qualitatively, but increasingly in quantitative terms. Dredging has often been uncontrolled and not always in the best public interest. In some areas there are several miles of dead reefs and bays with impoverished fauna and flora as a result of ill-planned and ill-managed dredging operations. In these areas water quality and benthic communities have not recovered quickly because of local conditions which we do not understand. Many areas destroyed by chronic turbidity and siltation show no signs of improvement, some even after many years.

EFFECTS OF DREDGING

Turbidity

Possibly the most damaging effect of dredging in most cases is clouding of the water by very fine suspended particles disturbed by the dredging operation. Most of this suspended material will usually be $CaCo_3$ sand fines, but depending on local sedimentological history, beds of other materials, (e.g. terrigenous clay deposits) if present, will also be disturbed by the dredge. In all operations which we have observed, enough of these fine materials remain in suspension to noticeably reduce submarine visibility for up to 2 years after the finish of dredging.

The primary effect of chronic turbidity is to cut down the amount of light which reaches plants on the bottom. Plants are the primary producers of food. In addition to food, they provide refuge for many species of animals. Without some minimum amount of light (the amount varies with the kind of plant), plants die and then the whole associated community is destroyed because of the loss of food and refuge. Of particular importance in these waters, however, is the effect of light loss on corals and other related reef organisms. Corals are animals, but the survival of reef building forms particularly, depends on the survival of symbiotic unicellular algae (zooxanthellae) which live within the coral tissues. There is a poorly understood nutrient relationship between the plant and animal, but it is known that when these corals lose their zooxanthellae they become unhealthy and die.

Turbidity due to fine sand sediment is usually not repulsive to the average swimmer, water skier and the like. These people are more tolerant of the chalky color than they are of the brown which results from mud caused by erosion and run-off. However, this turbid, chalky water is completely unattractive to snorkelers and SCUBA divers because one cannot see much and frequently there is nothing left to see.

The persistence of such turbidity depends on the interaction of several factors, the net result of which is surely different in each case. The settling time is primarily dependent on the size and shape of the particles and on the movement of the water which may either be slow enough to promote settling or strong enough to keep the particles in suspension and frequently continue suspending additional material from exposed beds of fines. Currents often transport plumes of such fines for great distances where they can seriously damage marine life far removed from the actual dredge site.

Siltation

Siltation is closely related to turbidity, being caused by solid particles. A great deal of siltation occurs during most dredging operations as heavier particles fall back to the bottom. Finer particles settle more slowly and siltation therefore can continue for some time after dredging and may occur at far removed sites. Its effects can be catastrophic for sessile organisms. If the rate of fallout is too great many sedentary organisms, particularly corals, are literally smothered because of their inability to cleanse themselves.

Beyond this, the coating of the substrate by silt size particles is disadvantageous to the settling of most invertebrate larvae and so recolonization is obstructed. Such surfaces are favored by some species of algae which give the advantage of stabilizing the bottom, but also effectively exclude the establishment of reef-builders. In fact, such alteration of the environment has been known to banish corals forever from an area where they were formerly well developed.

Change in Sediment Dynamics

Until very recently, dredging elicited alarm only when it resulted in undesirable and unexpected mass transport of sand from beaches. The most often encountered case is that of a beach adjacent to a dredge hole being denuded because its sand cover has slipped out to sea and into the hole created by the dredge. Geologists have long recognized that beaches are dynamic systems constantly undergoing changes in profile especially marked on a seasonal basis. If for any reason the nearby submarine topography is changed, currents and wave action will reshuffle the surrounding bottom to reach a new dynamic equilibrium. The result could be the redistribution of sand within an entire bay.

Release of Toxins from the Sediments

Very significant harm can be done by disrupting chemically unstable deposits. This problem is usually encountered during dredging in quiet lagoons, salt ponds, swamps, or the placid headwaters of some bays. In many such places, because strong water movement does not aerate the sediment to promote rapid decomposition of detritus, the bottom sediments are largely dark, organic-rich deposits, which have a characteristic foul, sulfide odor when disturbed. Undisturbed as they usually are, however, these sediments pose no great problems and, in fact, such habitats have a rich infauna which feeds basically on the detritus. Being only partially decomposed, however, these sediments are strongly reducing, that is, they require and will remove from the water when they are dispersed, a great deal of oxygen. Suspension of such sediments, therefore, in addition to problems of turbidity and siltation, will produce dirtier water, noxious odors and significantly decrease the dissolved oxygen in the water and the results can be severe for fish and other very active animals.

Effects on Associated Fauna

Although the destructive effects of ill-managed dredging operations can be observed directly only by underwater inspection, fishermen can frequently infer such changes from lowered catches of certain formerly abundant species. While the unfavorable effects of dredging do not usually cause direct harm to motile organisms, those which are closely associated with the reef will either migrate as their food and shelter are reduced or they will starve. Demersal fish and lobster are included here.

Deep Offshore Dredging

The chances are greater offshore of encountering large expanses of sand or gravel which is largely barren of attached macroorganisms, but benthic communities, including coral reefs, do exist on island shelf areas in the depth range for the offshore dredging project (20 - 30 meters, or 66 - 99 feet). We must recognize that organisms (parts of a benthic community) on such a dredge site will undoubtedly be destroyed.

Coral Reefs, the Platform, and Sand

In the West Indies, the zone of vigorous growth of reef corals extends down to about 25 meters. Many corals extend no deeper than about 30 meters, although reef communities (in which reef corals are present but not dominant) extend to 70 meters or more in the Caribbean. The factor which limits coral growth at depth is light. In deeper waters, coral maximize their light uptake by building horizontal thin, flat colonies instead of more rounded massive types. Near the lower limit of their depth range many species (if not most) are constructed in horizontal colonies spread over large areas. Although these colonies are mechanically more vulnerable to breakage and probably more vulnerable to sedimentation (which collects more readily on a flat surface), these are apparently not significant constraints in their natural, undisturbed environment. However, these colonies may be significantly more sensitive than their shallow water counterparts to the major results of dredging, sedimentation and turbidity.

Since the lower depth limits for many species of stony corals is within the proposed dredging depth range, it is reasonable to consider the possibility that a unit decrease in light intensity or increase in sedimentation resulting from dredging may have more marked effects on deep water reefs than on shallower ones. Other reef organisms which carry symbiotic algae in their tissues may be similarly affected by light intensity decreases. It is also possible that attached deeper water organisms in general which exist in a relatively low energy, low-sediment-load environment will be less able to rid themselves of sediment resulting from dredging.

Although it is common now to think of inshore sand as a renewable resource derived principally from the coral reef community, this concept may have to be modified for the open shelf of the Virgin Islands. Garrison (1971) found that surface sand from the shelf south of St. Thomas and

St. John away from terrestrial influences was composed of mollusc shell fragments, forams, and other carbonate fragments presumed to be derived from the breakdown of the algal carbonate nodules. Thus, at least the surface sand offshore is being produced by organisms *in situ* (at some currently unknown rate) and is not transported by water from a more distant shallow reef. It remains to be seen whether the same is true for the sands on other open shelf areas like Anegada, Barbuda, and Turks and Caicos Islands. Also, the rate of carbonate secretion, and ultimately sand production, of the open shelf community may be less rapid than that of the coral reef.

Living reefs are often only a thin veneer of regrowth on more massive reef structures built many thousands of years ago when the sea stood at a different level. It is likely that some of the large valuable deposits of sand which probably exist on shelf zones today were produced at earlier times of more active reef growth and (1) may be largely concealed so that they will be revealed only by sub-bottom profiling and coring and (2) are non-renewable in the sense that current reef growth is less than in former times so that sand production is reduced and is occurring in different localities.

Comments on Dredging Procedures

Regarding the type of dredging, it is often assumed that suction dredging is the least likely to cause any significant direct or indirect biological effect and hopper dredging minimizes the extent of spoil-water contact, therefore the intensity of short-term effects may be high, but the duration relatively small (Boyd *et al.*, 1972). While it is true that the mechanical damage resulting from cutterhead dredging is greater than that from suction dredging, it seems likely that these statements are more applicable to continental shores where increases in turbidity do not seriously endanger benthic communities.

Whether using a cutterhead or the suction method, any dredging operation piping into a series of large settling ponds (low energy level, long residence or settling time) is going to have less suspended sediment in the final overflow to the sea than a dredge pumping into a series of small hoppers or barges (high energy level, brief residence time). This is probably commercially advantageous in that for land fill operations any grain size will do (more or less), but for construction sand a smaller proportion of the very fine sediment is desirable. Thus, if the sediment being excavated into hoppers offshore contains a significant amount of fines, a very turbid effluent will be produced with its potential unfortunate biological consequences. It may be that currents over the shelf are sufficiently rapid so that turbidity will not persist long in one area, but we really know nothing of the effects of various time versus intensity of turbidity combinations on various marine organisms, and it would be best to err on the conservative side and set relatively stringent effluent requirements or, more practically, define the grain size distribution of sands which could be extracted (in effect, prelimiting the effluent since the dredger's engineers should have a clear idea of what grain sizes do and do not remain in the hoppers at various pumping rates).

RECOMMENDATIONS

The relationships of progress (in terms of shoreline development) to conservation are assessments which must be made locally. However, the importance of conservative management of marine resources to insular economics, especially when tourism is a large component, should not be underestimated.

Since a continuous sand supply is required for concrete production, land fill and beach reconstruction, which needs cannot be adequately met by maintenance and improvement of port facilities, we proposed, and have begun, a program of prospecting for mineable sand deposits offshore and in areas where ecological damage would be minimal.

In addition, there are several precautions which can be taken before and during any dredge operation. Such precautions can uncover problems likely to occur and minimize undesirable effects during operation.

Each person who desires permission to dredge (and dredging should not be allowed at a developer's whim) should ideally be required to submit to appropriate local authority sufficient justification for the operation, indicating how it would be in the public welfare. Specific boundaries of the proposed dredge area must be given and an evaluation made by competent professionals of the nature of the site, its suitability for such an operation and the probable effects of the dredging on the local and surrounding environments. A fee for each cubic yard of sand taken should be paid to the local government, and it is therefore desirable to have some sort of topographic survey of the dredge or spoil areas, or both, in order to determine the volume of material removed.

During the period of work, it is necessary to have some monitoring and control of conditions and methods to ensure compliance with requirements.

Several precautions can be taken in the actual operation. These include:

1. Proper diking to prevent runoff of suspended fines and to allow settling.

2. Controlling leaks in piping to prevent spilling of fines.

3. Dumping all spoils on land or barges.

4. Limiting the steepness and depth of the cut to avoid slumping of nearby sand into the hole.

5. Avoiding, where possible, direct reef removal.

6. Consideration of tides and currents where these may extend damage to nearby reef areas.

SUMMARY

Reef communities, especially their dominant and characteristic components, the corals, are extremely sensitive to prolonged turbidity and siltation. As individuals interested in the continued existence of both healthy, attractive environment, and continued economic growth (the latter being undeniably dependent to a great and increasing degree on the former) we must apply to environmental manipulations, conservative policies and procedures which are based on available knowledge and which are designed to minimize undesirable ecological damages and so achieve the most good for all considerations. We must also strive to increase our knowledge of environmental processes so that as stresses and demands on the environment increase, as they surely will, we can more effectively avoid disasters.